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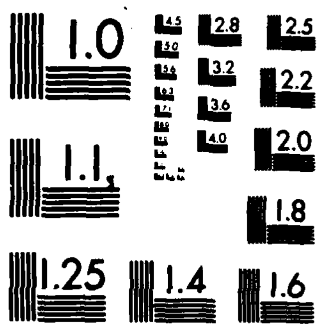

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HUMAN RESOURCES

WEAPON SYSTEM COSTING: AN INVESTIGATION INTO CAUSE-EFFECT RELATIONSHIPS

By

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Cause-Effect Cost Analysis was a technical effort that was terminated after approximately a year. Its purpose was to establish an approach to costing aircraft avionics, turbine engines, and missile systems that would not just estimate end costs, but could provide design engineers with insight as to how those systems generate ownership requirements which, in turn, incur costs. A methodology for analyzing avionics was created. Its major components consisted of two system design characteristics (technology and complexity) that were reasoned to be predictors of selected system ownership requirements. The major difficulty, which also contributed to the project's cancellation, was in defining and constructing the quantitative measures of avionics technology and complexity.

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This paper describes the technical effort up to the point of termination. The avionics approach, as well as the cause-effect concept of weapon system costing, represents only an investigation into causal modeling and does not reflect validated techniques ready for use.

AFHRL Technical Paper 83-13 June 1983

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I. INTRODUCTION

This paper summarizes the results of a study initiated by H. Anthony Baran, research psychologist, of the Air Force Human Resources Laboratory. The purpose of the study was to explore how a weapon system generates system ownership requirements in hopes of creating a new approach to weapon system costing. The new approach would involve cause-effect relationships between the phenomena that control the system design and the human and material requirements those phenomena percipitate. Unlike cost-estimating equations that estimate end costs based on technical experience, the causal relationships would provide insight into the circumstances which impact system ownership requirements that drive cost. Since the Department of Defense (DOD) is aware that the bulk of operation and support costs are incurred up front in system acquisition, it has emphasized the necessity for development of techniques for early and credible weapon system costing. Cause-effect relationships are among those techniques. The AFHRL study is introduced through an overview of how the DOD currently does its costing of weapon systems and the advantages and disadvantages to be associated with each method.

II. BACKGROUND

Parametric cost-estimating relationships are equations that attempt to describe mathematically the cost of an end item as a function of one or more variables. The equations are primarily used to develop probable cost estimates in the absence of hard data. The main premise behind cost estimating relationships (CERs) is that they are based on observations of what has happened in the past. The factors which prevailed

then should also hold during the estimated period. CERs are commonly derived in the following manner: candidate explanatory variables are normally selected as a result of interviews with engineers and manufacturers about the probable factors that impact end costs. Once the variables are identified to the best of the analyst's ability, their statistical properties are determined through multivariate regression analysis. If the equation is determined to be useful, i.e., if the statistical goals of the analyst are met, the equation is used[1].

Although it is not known where CERs were first developed, they have been used extensively by DOD since the early 1960s, as well as by private industry (Large, 1981, p. 2). Of the three basic methods used to estimate costs within DOD, parametric CERs are used most. There is good reason why CERs are popular in DOD. They provide what many Government analysts consider to be realistic cost estimates (Smith, 1971, p. 20). CERs also save manpower and time. For example, the accounting method, one of the three basic estimating methods, equates known units of costs to known units of output. It is an efficient method when there is sufficient cost information known about a design. In the early stages of weapon system acquisition, little is known about a piece of equipment other than minimum system characteristics and data such as engineering labor hours and labor rates. Other functional cost categories are almost nonexistent; this renders the accounting method inadequate. The cost analyst must resort to CERs to generate an estimate based on the available variables. An analyst may need to know what it will potentially cost to produce one fighter aircraft. The analyst who has no

cost proposal to evaluate will most likely use variables such as aircraft speed and airframe weight to predict the total number of direct labor hours it will take to produce one aircraft. By multiplying the estimated labor hours by the approximate labor rate, the analyst should have a reasonable cost estimate based on minimal input.

The second method used in DOD to estimate costs is the engineering method. This involves building a cost profile of the aircraft from the ground up. Estimates from a cross-section of work segments (e.g., drafting, engineering, manufacturing) are consolidated into a project estimate. This can be a laborious process, depending on the end item that is being estimated. For example, estimating the cost of an airframe may involve 4,000 separate estimates (Poindexter, 1976, p 22).

CERs can be used to generate a probable cost profile in short order since the majority of CERs are developed using computers. An analyst sitting at an interactive terminal can develop a functional relationship using a canned regression package in short order.

The biggest calling card for CERs is that they are useful in making cost estimates on fixed-wing aircraft, turbojet engines, missile systems, avionics components, and weaponry.

CERs are used on a variety of levels to estimate aircraft and weapon system costs. Typical CERs are those that derive cost estimates by type of aircraft structure, such as skin composition or machine plate; by functional cost elements, such as direct labor; and by acquisition phase. Airframe cost expressed as total direct labor hours as a function of airframe weight and speed has been used by DOD because of its estimating capability (Large, 1981, pp 3-8).

CERs are used individually or in clusters depending on the estimation requirement. They are also found embodded in life cycle cost (LCC) models in which they perform an invaluable function; they generate values for cost elements, such as replacement spares or maintenance of technical orders, when no historical or comparable data are available. LCC models used by the Air Force to estimate recurring or nonrecurring costs of aircraft systems rely heavily on CERs. Examples include the LSC model, CACE model, DAPCA, and PRICE models[2].

Of late, CERs have been subject to some criticism. Estimating relationships that are based on physical and performance variables may now be inadequate to estimate costs of technologically advanced aircraft systems because of no historical experience. Experts have observed that "cost data collected on even the latest weapon systems represent not the cost of current technology but current cost of technology 5 to 10 years in the past. In 20 years, electronics have gone from tubes to microminiaturization. Materials technology is rapidly improving airframe construction. Metal structure components are being replaced by plastic components. Which, if any, historical technology is similar enough to any proposed system to allow valid design and credible cost?" (Haese, 1977, p. 34)

CERs are also not sensitive to design changes or to advanced technology. CERs estimate end costs. They do not consider the implications of a design's composition and its probable impact on the human and material requirements in the operating environment. DOD has intensified its efforts in procuring weapon systems that are better and

cheaper to operate and maintain[3]. To procure the best design at least cost without jeopardizing mission requirements requires cost analysis techniques whose components are sensitive to the drivers of system ownership requirements. Although there are many LCC models in use today that do satisfactory jobs (for what they were programmed to do), none contain well-defined causal relationships between system design characteristics and ownership requirements. Because of this, researchers are constantly striving for unique methods to analyze system designs in terms of their absolute effects on manpower, material, and costs. This suggests a technique that should have an important role in weapon system acquisition: causal modeling.

Causal modeling attempts to explain the potential determinants of effects. The technique requires that three conditions be met before a causal relationship may be inferred: covariation and time ordering must exist between variables, and the relationship must not be contaminated by unknowns whose effects may be significant.

III. DISCUSSION

In 1980-81, the Air Force Human Resources Laboratory conducted a study on cause-effect relationships between system design and system ownership requirements using causal modeling concepts[4]. The purpose of the study was to develop a methodology to predict ownership requirements based on specific design inputs; the theory was that system design characteristics have a significant impact on the human and material requirements needed to operate and support the system in the field. The methodology, geared for aircraft avionics, would aid both systems

designers and support planners in assessing the impacts of alternative design configurations on ownership requirements. Two modifications to the methodology were also planned to extend its application to aircraft engines and missile systems, respectively. The study was divided into three phases to handle the aircraft avionics, engine, and missile system applications. Only phase one was completed. The other phases were terminated because of delays in technical progress.[5] The results of phase one are presented in this paper.

A prototype methodology was established for avionics. The methodology cons sted of a generic categorization of avionics equipment and a technique for analyzing these categories. The generic categories for avionics were transmitters, receivers, processors, sensors, displays, and controls. The technique consisted of a set of mathematical equations for selected ownership requirements as a function of two major design characteristics.

The generic categories seemed to encompass all of the representative electronic and nonelectronic functions that were to be associated with avionics equipment. Definitions for each of the categories are as follows:

Receivers - receive electromagnetic radiation including infrared. This category includes receivers for radar, communications, and instrument landing systems. Electronically, the receiver functions include the circuitry for radio frequency amplifiers, detectors, mixers, local oscillators, and noise filters.

Transmitters - transmit electromagnetic radiation including laser transmissions. Electronically, the transmitter functions include power amplifiers, modulators, filters, mixers, and oscillators.

Processors - process data, signals or information. This category includes computers, signal converters, processors, and synchronizers. Specific amplifiers and power supplies packaged in separate line replaceable units (LRUs) are included in this group. The signal-processing circuitry of tactical communications and navigation, instrument landing systems, encoder/transponders such as identify friend or foe (IFF), and similar units are also within this category.

Sensors - gather and sense signals of electromagnetic radiation, motion, and pressure. This category includes such devices as antennas, gyros, accelerometers, air-data probes, pressure probes, vidicons, and other associated circuitry.

Displays - display information to the aircrew. This category includes the various readout and display devices ranging from mechanical digital readouts to cathode-ray tubes.

Controls - are the devices by which the aircrew puts information into the avionics system. These devices include knobs, switches, and keyboards. Generally, the control panels associated with different avionics systems will be in this category.

This categorization scheme appeared ideal for use on a new system early in the design stage at which point functions could be easily identified but LRUs could not.

The categories are comprehensive. Every avionics function falls within one of the categories. Consequently, an LRU or functional parts of an LRU can be categorized. The assumption that drives this categorization scheme is that the LRU cost and reliability values can be apportioned among the functions by the percentage of circuitry devoted to each function.

The next step was the development of a technique for analyzing these categories. A set of causal relationships (mentioned previously as mathematical equations) was developed for each generic category of avionics equipment. The relationships use complexity and technology indices as the primary inputs to predict specific ownership requirements. A technology index was used because it appeared to be a theoretically plausible predictor of avionics ownership requirements[6]. It was assumed that the fundamental drivers of avionics cost and reliability would be governed by the size of the avionics box and its contents. The contents of the box are described by the kind of electronics which is, in turn, defined by function, technology age, and the amount of experience with that technology. A technology index and complexity index were developed for this purpose.

Technology age can be described in terms of electronic functions performed per unit weight. Such a relationship was developed by William A. Falkenstein of Ling-Temco-Vought (LTV) Aerospace Corporation in a paper given at the 33rd Annual Conference of the Society of Allied Weight Engineers, Inc. (SAWE) in 1974 (Falkenstein, 1974). This relationship was used as the technology index curve for this research and is illustrated in Figures 1 and 2.

The technology index indicates the density of electronic components. In the year 1945, one pound of avionics equipment contained approximately 10 vacuum tubes and their associated components. The term function denotes the activity (amplifying, gating, rectifying, etc.) of a single tube. Therefore, in 1945, avionics equipment performed approximately 10 functions per pound of electronics as indicated by point A of Figure 2. By 1955, improved technology led to the use of miniature tubes, and 1 pound of avionics contained approximately 20 miniature tubes. So, in 1955, 1 pound of avionics performed approximately 20 elementary functions (amplify, rectify, gating, etc.). This gives point B of Figure 2. As new technologies developed, the availability of medium scale integration (MSI), large scale integration (LSI), and very large scale integration (VLSI) allowed higher density electronics. These give the points D, E, and F of Figure 2, respectively.

The technology index indicates the type of electronic components used rather than the sophistication of the system. In the previous paragraph, the word "function" referred to the simple operations of amplify, rectify, gate, etc., performed by a single vacuum tube. Elsewhere in this report, the word "function" will refer to a higher level operation, such as receive, transmit, and process. The major problem with the technology index is that no equivalent metric exists for translating vacuum tube functions into microelectronic functions and vice versa.

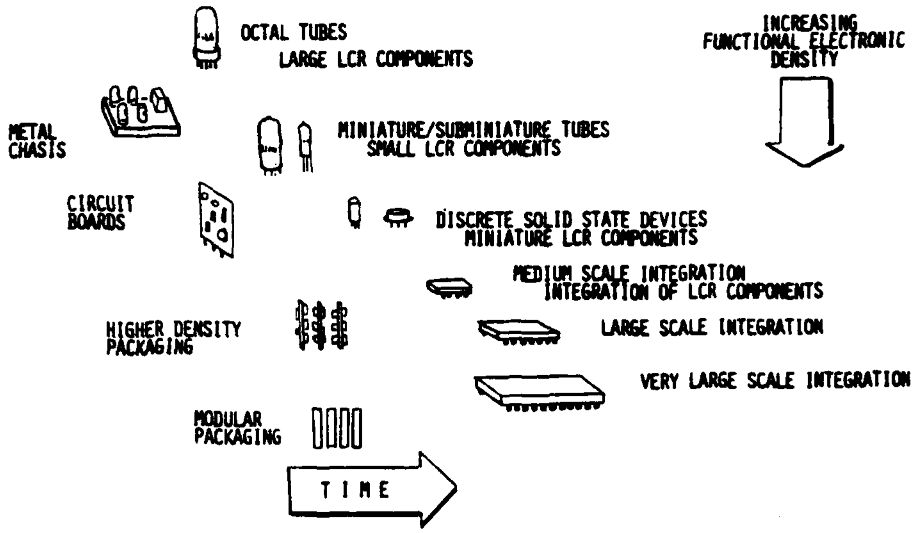
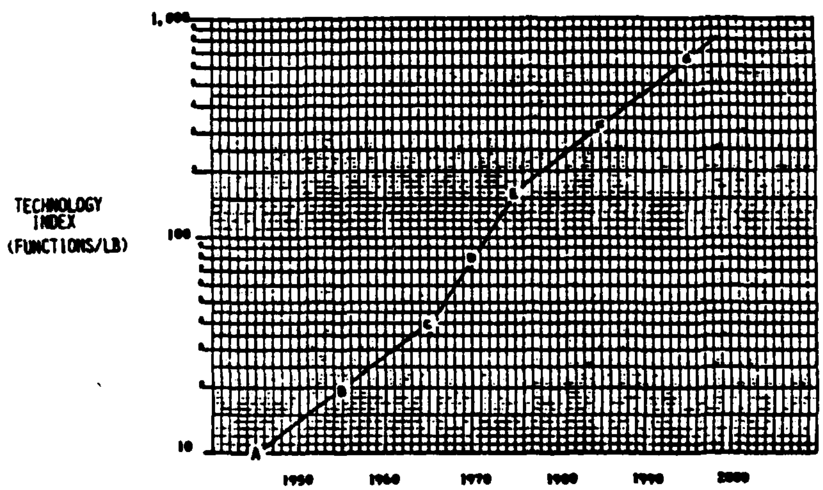


Figure 1. Technology Described in Terms of Electronics Type.



A - Large Vacuum Tubes. Discrete RLC
B - Miniature Tubes. Discrete RLC
C - Subminiature Tubes. Some Solid State Devices. Printed Circuit Boards. Some Integrated Circuits In Communications And Computers.
D - Medium Scale Level of Integration (MSI) of Microelectronic Integrated Circuits (MIC).
E - Large Scale Integration (LSI) of MIc. Lower Heat Dissipation (Lower Electrical Current) Allows Crowding of Components.
F - CMOS and Large Chip (Up to 3") Technology. Very Large Scale Integration (VLSI) Of MIC.
G - Technology Vague - May Include Molecular Electronics. Microlaser Applications. LSI Of Frequency Synthesizer. Conformal Antenna Arrays and Power Transmitter/Beam Forming Circuits.

Figure 2. Avionics Functional Density Increases With Advancing Technology

The technology index gives the vintage (period) of the electronics in the box. The complexity index is a measure of how much of this electronics is in the box. For a given vintage and kind of electronics, a measure of the amount of electronics (number of electronic functions) is weight. That is, if the period of the equipment determines the number of electronic functions per pound and the weight of the equipment is known, then the number of functions performed by the equipment is implied. The complexity index can be considered a scale of the number of electronic functions within the avionics subfunctions where:

$$\text{Complexity Index} = \frac{\text{Function Technology Index}}{100} \times \text{Function Circuitry Weight}$$

A complexity scale was developed for each avionics function category. Existing F-111 and F-16 avionics equipment was used to develop the complexity scale. For example, to develop the complexity scale for receivers, all LRUs with a receiver function were grouped by subsystem type and were listed along with the LRU weight, the percentage of the circuitry within the LRU devoted to the receiver function, and the technology index of each LRU. Engineering judgment was used to establish the technology indices for the LRUs. All the LRU weights were normalized for technology. The LRU weight percentage devoted to the receiver function became a point on the complexity scale.

The complexity index developed for the receiver category is shown in Figure 3. Also shown are preliminary complexity scale values for transmitters. To use the scale for a piece of avionics equipment that has a

receiver function, one compares the performance characteristics of the new equipment with the performance of receivers within the subsystem category of points existing on the receiver complexity scale.

Other variables were considered for constructing the causal relationships, the most critical being the amount of built-in test (BIT) circuitry in an LRU because of its support concept implications. The amount of BIT circuitry also impacts the complexity index of an avionics component. All the points on the complexity scale were adjusted to eliminate BIT potentially. It was assumed that if an avionics function contained BIT circuitry that could detect and isolate 95% of the faults, its complexity index would be increased by 10%. The gross 10% estimate was derived from an analysis of BIT circuitry within F-16 avionics equipment. The complexity index would be reduced by 10% if a piece of avionics equipment had 95% fault isolation capability. Again, subjective judgment figured largely in defining the BIT percentages and the complexity scale.

Next, causal relationships for the receiver function were developed. The relationships were developed to analyze the functional rather than the physical unit such as an LRU. The reasoning was that, during the early design phase, the physical packaging of equipment may not be known. Analysis of the functional unit allows this technique to be used early in the acquisition phases. These relationships were derived through multivariate regression.

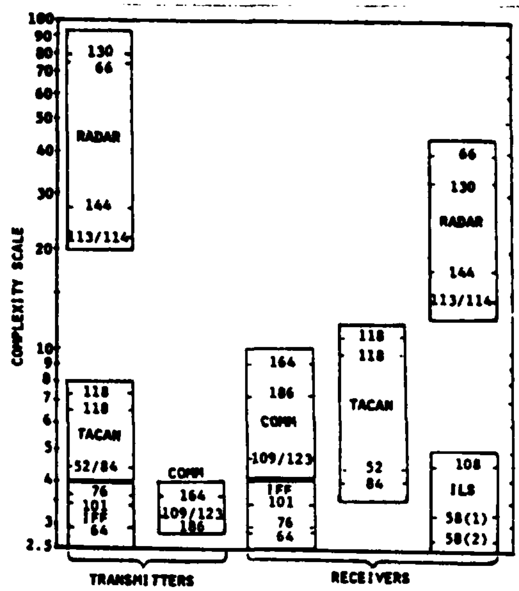


Figure 3. Complexity Scales Developed on Basis of F-111 and F-16 Transmitters and Receivers.

The relationships were developed from an F-111 and F-16 equipment data base containing 20 data points for the generic receiver category shown in Table 1. Data were collected at the physical unit level and were adjusted to reflect the functional unit by multiplying each data point by the percent of the LRU dedicated to the function. BIT circuitry was also subtracted from the functions using engineering judgment. The relationships that were developed are shown in Table 2. The appendix contains explanations of the predicted variables. An analysis-of-variance table for each equation is also included in the appendix.

A set of the relationships was tested on an F-15 radar receiver, a unit that was not in the data base. The predicted values came close to the actual F-15 values. The set of receiver relationships and test results are shown in Table 3. The relationships were also tested on an F-16 radar receiver. Those results are shown in Table 4.

The concept governing these relationships appears valid. The relationships were developed for individual categories of electronic and nonelectronic functions so that predictions could be based on trends of similar functions. Second, trend comparisions were made at similar technology levels through the technology and complexity indices. Third, the physical packaging of equipment did not appear to influence the basic predictions. Last, the primary inputs of the causal relationships, the complexity and technology indices, appeared to provide some design sensitivity to selected ownership requirements.

TABLE 1

Receivers in F-111 and F-16 Data Base

ATTACK RADAR	TERRAIN FOLLOWING RADAR	RADAR ALTIMETER
AN/APQ-113	AN/APQ-128	AN/APN-167
APQ-114		
APQ-130		
APQ-144		
APG- 66		
IFF	**ILS**	**TACAN**
AN/APX- 64	AN/ARN- 58	AN/ARN- 52
APX- 76	ARN-108	ARN- 84
APX-101		ARN-118 (F-111)
		ARN-118 (F-16)
HF	**VHF**	**UHF**
AN/ARC-123	AN/ARC-186	AN/ARC-109
		ARC-164

The methodology could be modified for application to engines and missile systems. The basic analysis of aircraft engines would be performed at the function level. The generic engine functions would include compressor, fuel monitoring, accessory gearbox, turbine and augmentor. Complexity and technology indices would be developed in a similar manner. The complexity index could indicate the number of piece parts in a function. A technology index for engines developed by Rand Corporation several years ago would be incorporated into the methodology.[7] In addition, a technique for considering the metallurgical composition of the engine would be developed (assuming that metallurgical composition of engines is a factor in driving certain ownership requirements).

The avionics methodology could almost be directly applied to missile systems. It was determined that the same aircraft avionics categories could work for missiles since aircraft avionics and missile avionics have similar functions even though the missions differ. Only four generic functions would be needed to describe missile avionics: sense, transmit, receive, and process. The complexity and technology indices would be the same (i.e., the missile indices would be constructed in the same manner as the aircraft avionics indices).

Although this study was exploratory, it did focus attention on several system design characteristics that indicated reasonable causal relationships with selected system ownership requirements. Research in this area could prove invaluable to DOD. Causal relationships could enable system designers and support planners to anticipate the impacts

TABLE 2

ESTIMATING RELATIONSHIPS

LRUs Per Function

$$LPF = .2062 + .1044(complexity)$$

SRUs Per Function

$$SPF = 121.4(complexity)^{.2984}(technology)^{-.7740}$$

LRU Unit Cost

$$UC = (10019.6)(.98354)^{technology}(1.10701)^{complexity}$$

SRU Unit Cost

$$SUC = (253.43)(complexity)^{.7267}$$

Mean Time Between Defective Removals

$$MTBDR = (2144)(1.01962)^{technology}(.91818)^{complexity}(.22292)^{utility}$$

Bench Check Serviceable Elapsed Time

$$BSET = .2267(complexity)^{.6428}$$

Bench Check on Repair Elapsed Time

$$BCRT^{*} = (FIAT + FIXT)/(efficiency)$$

where FIAT = fault isolate and test time = $.3237(complexity)^{.6650}$

*(see p. 29 for description of other components of this equation).

Integrated Test Adaptor Cost

$$ITAC = 3919(complexity)^{.4401}$$

Test Software Cost

$$SWC = 9867 + 1431(complexity)$$

Technical Order Pages

$$TOP = 69.64(complexity)^{.4366}$$

TABLE 3

F-15 Radar Receiver Test Case

Inputs	F-15	
Complexity	43	
Technology	120	
Utility	1	
Outputs	**F-15 Estimate**	**F-15 Actual**
Mean Time Between Defective Removal	125	130
Unit Cost	108,246	99,000
Bench Check Servicable Elapse Time	3.8	?
Bench Check & Repair Elapse Time	5.92	7.4

TABLE 4

F-16 Radar Receiver Test Case

PREDICTED SUPPORT VARIABLE	INPUTS	F-16 RADAR RECEIVER SUBFUNCTION	
		PREDICTED	ACTUAL
PARTITIONING			
- LRUS/SUBFUNCTION	COMPLEX	0.79	0.63
- SRUS/SUBFUNCTION	COMPLEX/TECH	8.25	6.93
COST			
- LRU UNIT COST	COMPLEX/TECH	68167	60121
- SRU UNIT COST	COMPLEX	3759	6607
ON-EQUIPMENT MAINTENANCE			
- MTBDR	COMPLEX/TECHNO/UTILITY	200	219
- REMOVE AND REPLACE TIME	% FIC/BIT/CONSTANTS	2.08	1.80
- CANNOT DUPLICATE TIME	BIT/CONSTANTS	0.92	1.30
- ON-EQUIPMENT REPAIR	% FIC/BIT/CONSTANTS	1.39	-
- CREW SIZE	BIT	2.2	2.2
OFF-EQUIPMENT MAINTENANCE			
- BENCH CHECK SERVICEABLE RATE	% FIC/# LRUS/% FI ERRORS	.136	.122
- BENCH CHECK SERVICEABLE ELAPSED TIME	COMPLEX	3.68	3.30
- BENCH CHECK & REPAIR ELAPSE TIME	COMPLEX/CONSTRUCT/TECH	5.73	5.60
- REPAIR MATERIAL COST	CONSTANT	147	-
SUPPORT EQUIPMENT			
- ITA UNIT COST	COMPLEX	20069	19987
- SOFTWARE COST	COMPLEX	68111	77358
- TEST STATION MMH/OH	CONSTANT	0.40	0.40
- TEST STATION MTBMA	CONSTANT	14.90	14.90
- TEST STATION INITIAL SPARES FACTOR	CONSTANT	-	-
- TEST STATION MATERIAL COST/OH	CONSTANT	-	-
TECHNICAL ORDER PAGES	COMPLEX	352	371

of advanced technological designs on human and material resources through an understanding of the interrelationships of design, technology, and system ownership requirements.

FOOTNOTES

[1]Statistical goals usually include the following: establishing an R^2 value; setting a standard error of the estimate percentage of mean response; an alpha value for statistical significance; and reviewing residuals for discernible patterns. These criteria should help the researcher decide whether a useful equation has been developed.

[2]LSC stands for Logistics Support Cost Model; CACE is Cost Analysis Cost Estimating; DAPCA is Development and Production Costs of Aircraft; PRICE is Programmed Review of Information for Costing and Evaluation.

[3]DOD has published numerous documents that stress the procurement of weapon systems that will prove to be economical to operate and support in the field. Such documents include DOD Directive 5000.2 Major System Acquisition Process; DOD Directive 5000.39, Acquisition and Management of Integrated Logistics Support for Systems and Equipment, and DOD Directive 5000.4, OSD Cost Analysis Improvement Group.

[4]AFHRL had assistance from General Dynamics Corporation, Fort Worth and Convair Divisions under contract number F33615-79-C-0028.

[5]Phase two, the engine study, was aborted to avoid duplication of effort in light of Rand Corporation's headway in engine cost estimating techniques. Phase three, the missile application, was ended because the contractor could not develop costing relationships for missiles. Despite unresolved technical difficulties, phase one was permitted to run its natural course since its constructs and the preliminary relationships for avionics costing had the strong appeal of "gut level" credibility. The difficulties, which undermined that credibility, lay in: 1) defining and quantifying the measures of avionics technology and complexity; and 2) proceduralizing the definition of avionics functions over time.

[6]John M. Jermier writes that one need not rule out all possible causes in a causal inquiry if there is "sufficient reasonableness" to expect a relationship between two or more variables; see, e.g., his article "Causal Analysis in the Organizational Sciences and Alternative Model Specifications and Evaluation," The Academy of Management Review, III (April 1978), pp. 326-37.

[7]The time-of-arrival equation was developed specifically for military jet engines. It is essentially a technology index composed of engine characteristics such as turbine inlet temperature, total pressure, weight, thrust and fuel consumption. J.L. Birkler, et al, describe this equation in Development and Production Cost Estimating Relationships for Aircraft Turbine Engines (Sarta Monica, California: Rand Corporation, 1982).

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APPENDIX A

DEVELOPMENT OF ESTIMATING RELATIONSHIPS

Partitioning Variables

The partitioning variables help to indicate how the design engineers will partition the electronics. Although this can vary from one design engineer to another, it was reasoned that the complexity and technology of the equipment can explain some of the variation in packaging.

LRUs per function (LPF) is derived from regression analysis:

$$LPF = .2062 + .0144(\text{complexity})$$

SRUs per function (SPF) was derived from regression analysis:

$$SPF = 121.4(\text{complexity})^{.2984} (\text{technology})^{.7740}$$

Cost Variables

The significance of the cost variables is clear. Historical unit cost data will show a great deal of variation for some LRUs. For instance, a spare part produced during a production run can cost as little as one-fifth the cost of the same spare produced as a separate run. This is due to the large initial cost of a run. Furthermore, some "hot mockups" are purchased for training purposes and are much more expensive than the normal unit.

This cost variation will occur for any avionics system and is not adequately reflected in the Air Force Logistics Command data (e.g., K051 records). In order to get valid average unit cost data, it was necessary to average several purchase records for each LRU.

The LRU unit cost (UC) was derived from regression analysis:

$$UC = \text{avg. LRU unit spares cost (FY75\$)}$$
$$= (10019.6)(.98354)^{\text{technology}}(1.10701)^{\text{complexity}}$$

The SRU unit cost (SUC) was derived from regression analysis:

$$SUC = \text{avg. spares unit cost of the receive/transmit function (FY75\$)}$$
$$= (253.43)(\text{complexity})^{.7267}$$

On-Equipment Maintenance Variables

The on-equipment maintenance variables depend greatly on the built-in test and fault isolation capabilities of avionics equipment.

Mean time between defective removal (MTBDR) was derived from regression analysis:

$$MTBDR = \text{avg. \# of flight hours between removals of a defective unit}$$
$$= (2144)(1.01962)^{\text{technology}}(.91818)^{\text{complexity}}(.22292)^{\text{utility}}$$

where

$$\text{utility} = \begin{cases} 0 & \text{for communications equipment: and} \\ 1 & \text{otherwise.} \end{cases}$$

The variable, utility, accounts for variations in MTBDR for certain equipment which may have greater usage demands placed on them, which, in turn, precipitates higher than expected removals.

The elasped time for remove and replace, cannot duplicate, and on-equipment repair are derived from estimates of the times required to set up, verify, troubleshoot, remove and replace, repair, LRUs and close up the unit.

The set-up time is the time required (1) to access the LRU, (2) to connect power and cooling air or start the auxilliary power unit (APU), and (3) to position work stands. Therefore,

set-up time = access time + electric power time + cooling air time + maintenance stand time

where

access time = .16 hr.

electric power time = $\begin{cases} .16 \text{ hr if electric power is required;} \\ 0 \text{ otherwise.} \end{cases}$

cooling air time = $\begin{cases} .16 \text{ hr if cooling air is required;} \\ 0 \text{ otherwise.} \end{cases}$

stand time = $\begin{cases} .08 \text{ hr if a stand is required;} \\ 0 \text{ otherwise.} \end{cases}$

APU time = $\begin{cases} .08 \text{ hr if installed in aircraft;} \\ 0 \text{ otherwise.} \end{cases}$

These time estimates were obtained from analysis of F-16 and F-111 maintenance actions.

Verify time is the elapsed time required to functional check the system after LRU replacement.

$$\text{Verify time} = \begin{cases} .44 \text{ hr if equipment has BIT capability; and} \\ .8 \text{ hr otherwise} \end{cases}$$

The verify times are obtained from analysis of F-16 and F-111 maintenance actions.

Troubleshoot time = .33(FIC) + .8(1-FIC)

where

FIC = decimal fraction of the time that built-in test/self-test can fault isolate to the LRU level.

This equation is obtained by comparing F-111 times (very little built-in test/self-test circuitry) with F-16 times (.95% fault isolation capabilities).

Remove and replace LRU time is the elapsed time required to remove and replace the faulty component.

Remove and replace LRU time = set-up time + troubleshoot time + remove and replace LRU time + verify time + close-up time

On-aircraft repair time = .5(set-up time) + .5(troubleshoot time) + repair time + .5(verify time) + .5(close-up time)

Cannot duplicate time = .5(set-up time) + verify time + .5(close-up time)

$$\text{Crew size} = \begin{cases} 2.2 \text{ if the equipment has BIT capability; and} \\ 2.4 \text{ otherwise.} \end{cases}$$

The two values for crew size are averages from F-16 and F-111 data, respectively.

Off-Equipment Maintenance Variables

The bench check serviceable rate (BSCR) can be predicted theoretically.

BSCR = decimal fraction of time a good LRU is removed

= (1-FIC) (1-1/NLRU) + FIE,

where

FIC = decimal fraction of the time which the equipment identifies an LRU to be bad.

and

FIE = decimal fraction of time which the equipment improperly identifies an LRU to be bad when in fact the LRU is servicable

NLRU = the number of LRUs in the function.

Both FIC and FIE should be in specification of future avionics equipment. The value of NLRU can be estimated with the help of the partioning variables.

Bench check serviceable elapsed time (BSET) was derived from regression analysis:

$$\text{BSET} = .2267(\text{complexity})^{.6428}$$

Bench check and repair elapsed time (BCRT) is:

$$\text{BCRT} = (\text{FIAT} + \text{FIXT})/(\text{efficiency})$$

where

FIAT = fault isolate and test time = $.2267(\text{complexity})^{.6418}$ was derived from regression analysis:

FIXT = fix time

$$= \begin{cases} .25 & \text{for remove \& replace of plug-in model} \\ .33 & \text{for discrete components (2-4 pins)} \\ .47 & \text{for MSI components (14 pins)} \\ .60 & \text{for LSI components (24 pins)} \\ .73 & \text{for VLSI components (36 pins)} \end{cases}$$

and

efficiency = .6667 is an adjustment factor which accounts for the skill differences between commercial maintenance personnel and Air Force intermediate shop maintenance personnel. (Contractor's subjective estimate).

Repair material cost (RMC) was derived from historical averages;

RMC = $47

The average replacement part cost was $43, and 10% was added for miscellaneous material cost.

Support Equipment Variables

Integrated Test Adaptor Cost was derived from regression analysis:

$$ITAC = 3919(\text{complexity})^{.4401}$$

Test Software Cost (SWC) was derived from regression analysis:

$$SWC = 4867 + 1431(\text{complexity})$$

The Test Station Cost (TSC) was averaged from F-16 test stations:

TSC = 800,000

The Test Station Man Hours (TSMH) is the average number of manhours per test station repair:

$$TSMH = .4$$

The Test Mean Time Between Maintenance Action (TMTBMA) is the average test time between test station repairs.

$$TMTBMA = 14.9$$

The Technical Order Pages (TOP) was derived from regression analysis:

$$TOP = 69.64(\text{complexity})^{.4366}$$

LRUs PER FUNCTION

LPF= .2062 + .0144(complexity)

	OBSERVATIONS	CROSS REF:	DATA PT	DISK R(
1	8	71BA0		
2	9	71EA0		
3	11	71AA0		
4	15	73CA0		
5	16	73KB0		
6	17	73BD0		
7	19	73PK0		
8	20	73VA0		
9	21	74AB0		

THE INPUT VARIABLES ARE

N	LRUS/SUBF Y	COMPLEX X 1	N
1	0.20	4.40	1
2	0.20	4.00	2
3	0.30	11.00	3
4	0.30	2.00	4
5	0.50	8.40	5
6	0.40	16.20	6
7	1.00	37.20	7
8	0.40	20.00	8
9	0.70	45.40	9

(continued p. 33)

LRUs PER FUNCTION(Continued):

```
----- REGRESSION OF INPUTS FOR OPTION 1     Y=a+b*X1+c*X2  --------
      CONFIDENCE LEVEL =  0.5


CORRELATION MATRIX  (Y is last column)
     1.00000     0.85070
     0.85070     1.00000

----------------------------- NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  1      ENTERED IS       0.995982302     F =
 18.33366015

VARIABLE            COEF             STAND ERR        NAME
 1              0.014428813    3.36981E-03   COMPLEX
CONSTANT        0.206208705

ANOVA TABLE
SOURCE          DF                  SS                    MS   OVERALL F
-----------------------------------------------------------------
TOTAL           8                0.542222222
REGRESSION      1                0.392399594    0.392399594    18.333
RESIDUAL        7                0.149822629    0.021403233
-----------------------------------------------

THE OVERALL CONFIDENCE IS        0.995982302
THE PER CENT OF ERROR EXPLAINED IS             72.3687775

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS       25.23
THE AVERAGE ERROR IS             0.109902749

OBSERV       EST Y        TRUE Y       ERROR        % ERROR      NAME
  1          0.27         0.20        -0.07        -34.85        71BA0
  2          0.26         0.20        -0.06        -31.96        71EA0
  3          0.36         0.30        -0.06        -21.64        71AA0
  4          0.24         0.30         0.06         21.64        73CA0
  5          0.33         0.50         0.17         34.52        73KB0
  6          0.44         0.40        -0.04         -9.99        73BD0
  7          0.74         1.00         0.26         25.70        73PK0
  8          0.49         0.40        -0.09        -23.70        73VA0
  9          0.86         0.70        -0.16        -23.04        74AB0

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION
    VAR          PARTIAL F STAT        CONF.         NAME

 1               18.33366014     0.995982302    COMPLEX
```

SRUs PER FUNCTION

$$SPF = 121.4(\text{complexity})^{.2984}(\text{technology})^{-.7740}$$

	OBSERVATIONS CROSS REF:	DATA PT	DISK I
1	1	74AB0R	
2	2	65AA0R	
3	3	65AA0T	
4	4	71BA0R	
5	5	63AA0R	
6	6	63AA0T	
7	7	62CA0R	
8	8	62CA0T	
9	9	74AC0T	

THE INPUT VARIABLES ARE

N	SRU/SUBF Y	COMPLEX X 1	TECHNO X 2	N
1	7.70	46.00	135.00	1
2	4.00	3.40	135.00	2
3	4.00	3.40	135.00	3
4	6.40	4.50	80.00	4
5	9.10	9.00	135.00	5
6	3.90	3.60	135.00	6
7	5.60	7.20	135.00	7
8	2.40	3.10	135.00	8
9	9.00	83.70	135.00	9

(continued p. 35)

SRUs PER FUNCTION(Continued):

```
----- REGRESSION OF INPUTS FOR OPTION 2    Y=a*X1↑b*X2↑c  --------
      CONFIDENCE LEVEL =  0.5


CORRELATION MATRIX  (Y is last column)
     1.00000     0.17930     0.75351
     0.17930     1.00000    -0.15429
     0.75351    -0.15429     1.00000

------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  1     ENTERED IS      0.981384752    F =
 9.195523859

VARIABLE              COEF             STAND ERR      NAME
 1                0.278613247      0.091878421    COMPLEX
CONSTANT          2.970758096

ANOVA TABLE
SOURCE            DF                  SS                     MS   OVERALL F
-------------------------------------------------------------------------
TOTAL             8               1.630751505
REGRESSION        1               0.925911042     0.925911042     9.1955
RESIDUAL          7               0.704840463     0.100691495
-----------------------------------------------------

THE OVERALL CONFIDENCE IS       0.981384752
THE PER CENT OF ERROR EXPLAINED IS             56.77818105

------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  2     ENTERED IS      0.734026137    F =
 1.501906695

VARIABLE              COEF             STAND ERR      NAME
 1                0 298436377      0.090213657    COMPLEX
 2               -0.774007557      0.631573246    TECHNO
CONSTANT          121.4069733

ANOVA TABLE
SOURCE            DF                  SS                     MS   OVERALL F
-------------------------------------------------------------------------
TOTAL             8               1.630751505
REGRESSION        2               1.067022449     0.533511224     5.67837
RESIDUAL          6               0.563729056     0.093954843
-----------------------------------------------------

THE OVERALL CONFIDENCE IS       0.946703889
THE PER CENT OF ERROR EXPLAINED IS             65.43133309
```

(continued p. 36)

SRUs PER FUNCTION(Continued):

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS 16.03
THE AVERAGE ERROR IS 0.917246050

OBSERV	EST Y	TRUE Y	ERROR	% ERROR	NAME
1	8.54	7.70	-0.84	-10.94	74AE0F
2	3.93	4.00	0.07	1.85	65AA0F
3	3.93	4.00	0.07	1.85	65AA0T
4	6.40	6.40	-0.00	-0.00	71BA0F
5	5.25	9.10	3.85	42.31	63AA0F
6	3.99	3.90	-0.09	-2.40	63AA0T
7	4.91	5.60	0.69	12.30	62CA0F
8	3.82	2.40	-1.42	-59.14	62CA0T
9	10.21	9.00	-1.21	-13.48	74AC0T

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION

VAR	PARTIAL F STAT	CONF.	NAME
1	10.94356800	0.983843258	COMPLEX
2	1.501906695	0.734026167	TECHNO

PARTIAL SIGNIFICANCE OF VARIABLES NOT IN REGRESSION

VAR	PARTIAL F STAT	CONF	NAME

LRU UNIT COST

$$UC = (10019.6)(.98354)^{\text{technology}}(1.10701)^{\text{complexity}}$$

OBSERVATIONS CROSS REF: DATA PT DISK I

1	2	63AA0
2	3	63AA0
3	4	62CA0
4	7	65AA0
5	9	71EA0
6	11	71AA0
7	12	71CA0
8	13	71CB0
9	14	71BA0
10	15	73CA0
11	16	73KB0
12	17	73BD0
13	18	73JC0
14	19	73PK0
15	20	73VA0
16	21	74AB0

THE INPUT VARIABLES ARE

N	COST Y	TECHNO X 1	COMPLEX X 2	N
1	6671.00	60.00	4.70	1
2	2461.00	135.00	9.00	2
3	2538.00	135.00	7.20	3
4	2818.00	135.00	3.40	4
5	2157.00	80.00	4.00	5
6	2454.00	135.00	11.00	6
7	7660.00	50.00	2.70	7
8	7680.00	50.00	3.20	8
9	3637.00	80.00	4.50	9
10	2559.00	60.00	2.00	10
11	10168.00	60.00	8.40	11
12	25528.00	40.00	16.20	12
13	22000.00	40.00	16.20	13
14	167357.00	60.00	37.20	14
15	54084.00	50.00	20.00	15
16	60121.00	135.00	40.90	16

(continued p.38)

LRU UNIT COST(Continued):

```
----- REGRESSION OF INPUTS FOR OPTION 3    Y=a*b↑X1*c↑X2  --------
          CONFIDENCE LEVEL =  0.5



CORRELATION MATRIX  (Y is last column)
     1.00000     0.07440    -0.40427
     0.07440     1.00000     0.84868
    -0.40427     0.84868     1.00000


------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  2     ENTERED IS      0.999891997    F =
 36.04592652


VARIABLE           COEF            STAND ERR       NAME
 2               1.102566394     0.016263054   COMPLEX
CONSTANT         2715.630863


ANOVA TABLE
SOURCE           DF                  SS                   MS    OVERALL F
------------------------------------------------------------------
TOTAL            15                28.15187104
REGRESSION       1                 20.27658084      20.27658084    36.045
RESIDUAL         14                7.875290200      0.562520729
----------------------------------------------------

THE OVERALL CONFIDENCE IS        0.999891997
THE PER CENT OF ERROR EXPLAINED IS               72.02569524

------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  1     ENTERED IS      0.999943971    F =
 47.5638315


VARIABLE           COEF            STAND ERR       NAME
 1               0.983542908     2.40610E-03   TECHNO
 2               1.107011504     7.84088E-03   COMPLEX
CONSTANT         10019.6045


ANOVA TABLE
SOURCE           DF                  SS                   MS    OVERALL F
------------------------------------------------------------------
TOTAL            15                28.15187104
REGRESSION       2                 26.46144344      13.23072172    101.749
RESIDUAL         13                1.690427604      0.130032893
----------------------------------------------------

THE OVERALL CONFIDENCE IS        0.999993203
THE PER CENT OF ERROR EXPLAINED IS               93.99532769
```

(continued p. 39)

LRU UNIT COST(Continued):

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS 26.90
THE AVERAGE ERROR IS 3273.314255

OBSERV	EST Y	TRUE Y	ERROR	% ERROR	NAME
1	5969.86	6671.00	701.14	10.51	63AA0
2	2662.67	2461.00	-201.67	-8.19	63AA0
3	2217.39	2538.00	320.61	12.63	62CA0
4	1506.83	2818.00	1311.17	46.53	65AA0
5	3989.55	2157.00	-1832.55	-84.96	71EA0
6	3263.03	2454.00	-809.03	-32.97	71AA0
7	5750.78	7660.00	1909.22	24.92	71CA0
8	6050.66	7680.00	1629.34	21.22	71CB0
9	4197.59	3637.00	-560.59	-15.41	71BA0
10	4536.84	2559.00	-1977.84	-77.29	73CA0
11	8696.15	10168.00	1471.85	14.48	73KB0
12	26782.28	25528.00	-1254.28	-4.91	73BD0
13	26782.28	22000.00	-4782.28	-21.74	73JC0
14	162520.68	167357.00	4836.32	2.89	73PK0
15	33385.57	54084.00	20698.43	38.27	73VA0
16	68197.73	60121.00	-8076.73	-13.43	74AB0

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION

VAR	PARTIAL F STAT	CONF.	NAME
1	47.5638315	0.999943971	TECHNO
2	168.1143938	0.999997851	COMPLEX

SRU UNIT COST

$$SUC = (253.43)(\text{complexity})^{.7267}$$

	OBSERVATIONS CROSS REF:	DATA PT	I
1	1	74AB0R	
2	2	65AA0R	
3	3	65AA0T	
4	4	71BA0P	
5	5	63AA0R	
6	6	63AA0T	
7	9	74AC0T	

THE INPUT VARIABLES ARE

N	ASRU COST Y	COMPLEX X 1	TECHNO X 2	N
1	6607.00	46.00	135.00	1
2	726.00	3.40	135.00	2
3	726.00	3.40	135.00	3
4	573.00	4.50	80.00	4
5	769.00	9.00	135.00	5
6	769.00	3.60	135.00	6
7	5075.00	83.70	135.00	7

(continued p. 41)

SRU UNIT COST(Continued):

```
----- REGRESSION OF INPUTS FOR OPTION 2     Y=a*X1↑b*X2↑c  --------
      CONFIDENCE LEVEL =  0.5


CORRELATION MATRIX  (Y is last column)
     1.00000     0.24174     0.94566
     0.24174     1.00000     0.34696
     0.94566     0.34696     1.00000


------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  1      ENTERED IS       0.998036404     F =
 42.28914797


VARIABLE              COEF              STAND ERR       NAME
 1                  0.726683968    0.111745775   COMPLEX
CONSTANT            253.429932


ANOVA TABLE
SOURCE              DF                   SS                   MS   OVERALL F
-----------------------------------------------------------------
TOTAL               6              6.39897142
REGRESSION          1              5.722392152    5.722392152    42.289
RESIDUAL            5              0.676579268    0.135315854
---------------------------------------------------

THE OVERALL CONFIDENCE IS          0.998036404
THE PER CENT OF ERROR EXPLAINED IS                89.42674966

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS          29.12
THE AVERAGE ERROR IS               681.8478735

OBSERV        EST Y        TRUE Y        ERROR         % ERROR       NAME
   1        4094.09      6607.00      2512.91         38.03        74AB0P
   2         616.70       726.00       109.30         15.05        65AA0P
   3         616.70       726.00       109.30         15.05        65AA0T
   4         756.03       573.00      -183.03        -31.94        71BA0P
   5        1251.10       769.00      -482.10        -62.69        63AA0P
   6         642.86       769.00       126.14         16.40        63AA0T
   7        6325.16      5075.00     -1250.16        -24.63        74AC0T

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION
     VAR           PARTIAL F STAT          CONF.          NAME

 1                 42.28914796     0.995825840    COMPLEX


PARTIAL SIGNIFICANCE OF VARIABLES NOT IN REGRESSION

VAR           PARTIAL F STAT          CONF       NAME
 2                 0.655023851     0.459213480    TECHNO
```

MEAN TIME BETWEEN DEFECTIVE REMOVALS

$$MTBDR = (2144)(1.01962)^{technology}(.91818)^{complexity}(.22292)^{utility}$$

OBSERVATIONS CROSS REF: DATA PT

1	1	61AA0
2	2	63AA0
3	3	63AA0
4	4	62CA0
5	5	65AA0
6	6	65BA0
7	7	65AA0
8	9	71EA0
9	10	71ZA0
10	11	71AA0
11	12	71CA0
12	13	71CB0
13	14	71BA0
14	15	73CA0
15	16	73KB0
16	17	73BD0
17	18	73JC0
18	19	73PK0
19	20	73VA0
20	21	74AB0

THE INPUT VARIABLES ARE

N	MTBDR Y	TECHNO X 1	COMPLEX X 2	UTILITY X 3	N
1	307.00	60.00	4.70	2.00	1
2	150.00	60.00	4.70	2.00	2
3	456.00	135.00	9.00	2.00	3
4	654.00	135.00	7.20	2.00	4
5	905.00	50.00	2.90	1.00	5
6	1010.00	50.00	2.40	1.00	6
7	2361.00	135.00	3.40	1.00	7
8	1467.00	80.00	4.00	1.00	8
9	4581.00	135.00	9.70	1.00	9
10	4177.00	135.00	11.00	1.00	10

(continued p. 43)

MEAN TIME BETWEEN DEFECTIVE REMOVALS(Continued):

11	1608.00	50.00	2.70	1.00	11
12	1173.00	50.00	3.20	1.00	12
13	1964.00	80.00	4.50	1.00	13
14	490.00	60.00	2.00	2.00	14
15	202.00	60.00	8.40	2.00	15
16	183.00	40.00	16.20	1.00	16
17	128.00	40.00	16.20	1.00	17
18	91.00	60.00	37.20	1.00	18
19	168.00	50.00	20.00	1.00	19
20	219.00	135.00	40.90	1.00	20

(continued p. 44)

Mean Time Between Defective Removals(continued):

----- REGRESSION OF INPUTS FOR OPTION 3   Y=a*b↑X1*c↑X2 --------
CONFIDENCE LEVEL = 0.5

CORRELATION MATRIX (Y is last column)

1.00000	0.13621	0.08772	0.46002
0.13621	1.00000	-0.27465	-0.53816
0.08772	-0.27465	1.00000	-0.31715
0.46002	-0.53816	-0.31715	1.00000

------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE 2 ENTERED IS 0.986214257 F =
7.338239574

VARIABLE	COEF	STAND ERR	NAME
2	0.943047895	0.021646353	COMPLEX
CONSTANT	1088.225032		

ANOVA TABLE

SOURCE	DF	SS	MS	OVERALL F
TOTAL	19	27.50176129		
REGRESSION	1	7.96481983	7.96481983	7.33823
RESIDUAL	18	19.53694146	1.085385637	

THE OVERALL CONFIDENCE IS 0.986214257
THE PER CENT OF ERROR EXPLAINED IS 28.96112634

------------------------------ NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE 1 ENTERED IS 0.996521100 F =
11.71423952

VARIABLE	COEF	STAND ERR	NAME
1	1.017222801	4.98923E-03	TECHNO
2	0.935472996	0.017299706	COMPLEX
CONSTANT	302.176393		

ANOVA TABLE

SOURCE	DF	SS	MS	OVERALL F
TOTAL	19	27.50176129		
REGRESSION	2	15.93509575	7.967547874	11.7102
RESIDUAL	17	11.56666554	0.680392091	

THE OVERALL CONFIDENCE IS 0.996517207
THE PER CENT OF ERROR EXPLAINED IS 57.94209171

Continued p.45)

Mean Time Between Defective Removals(Continued):

```
---------------------------- NEXT ITERATION ----------------------
CONFIDENCE OF VARIABLE  3     ENTERED IS      0.999967668     F =
 46.32170487
```

VARIABLE	COEF	STAND ERR	NAME
1	1.019616009	2.62856E-03	TECHNO
2	0.918176142	9.44226E-03	COMPLEX
3	0.222921617	0.220530994	UTILITY
CONSTANT	2144.098142		

ANOVA TABLE

SOURCE	DF	SS	MS	OVERALL F
TOTAL	19	27.50176129		
REGRESSION	3	24.53222364	8.177407881	44.0602
RESIDUAL	16	2.969537644	0.185596103	

THE OVERALL CONFIDENCE IS   0.999961728
THE PER CENT OF ERROR EXPLAINED IS   89.20237285

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS   35.48
THE AVERAGE ERROR IS   421.3861907

OBSERV	EST Y	TRUE Y	ERROR	% ERROR	NAME
1	228.82	307.00	78.18	25.46	61AA0
2	228.82	150.00	-78.82	-52.55	63AA0
3	680.50	456.00	-224.50	-49.23	63AA0
4	793.53	654.00	-139.53	-21.33	63CA0
5	985.63	905.00	-80.63	-8.91	65AA0
6	1028.61	1010.00	-18.61	-1.84	65BA0
7	4923.71	2361.00	-2562.71	-108.54	65AA0
8	1607.06	1467.00	-140.06	-9.55	71EA0
9	2875.59	4581.00	1705.41	37.23	71ZA0
10	2573.53	4177.00	1603.47	38.39	71AA0
11	1002.60	1608.00	605.40	37.65	71CA0
12	960.71	1173.00	212.29	18.10	71CB0
13	1539.91	1964.00	424.09	21.59	71BA0
14	288.14	490.00	201.86	41.20	73CA0
15	166.85	202.00	35.15	17.40	73KB0
16	260.77	183.00	-77.77	-42.50	73BD0
17	260.77	128.00	-132.77	-103.73	73JC0
18	64.04	91.00	26.96	29.63	73PK0
19	228.95	168.00	-60.95	-36.28	73VA0
20	200.46	219.00	18.54	8.47	74AB0

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION

VAR	PARTIAL F STAT	CONF.	NAME
1	54.6180118	0.999981256	TECHNO
2	81.73685646	0.999994668	COMPLEX
3	46.32170487	0.999967668	UTILITY

Bench Check Serviceable Elapsed Time

$$BSET = .2267(\text{complexity})^{.6428}$$

OBSERVATIONS	CROSS REF:	DATA PT
1	1	63AA0R
2	2	63AA0T
3	3	65AA0R
4	4	65AA0T
5	5	74AB0R
6	6	74AC0T

THE INPUT VARIABLES ARE

N	BCS Y	COMPLEX X 1	N
1	1.50	8.80	1
2	0.60	3.80	2
3	0.40	3.40	3
4	0.40	3.40	4
5	2.30	40.90	5
6	3.30	75.30	6

(continued p.47)

Bench Check Serviceable Elapsed Time(Continued):

```
----- REGRESSION OF INPUTS FOR OPTION 2    Y=a*X1↑b*X2↑c  --------
      CONFIDENCE LEVEL =  0.5


CORRELATION MATRIX  (Y is last column)
    1.00000    0.95575
    0.95575    1.00000


------------------------------ NEXT ITERATION ---------------------
CONFIDENCE OF VARIABLE  1     ENTERED IS      0.995816937    F =
 42.22277712

VARIABLE            COEF           STAND ERR      NAME
 1              0 642784727    0.098921832   COMPLEX
CONSTANT        0 226743568

ANOVA TABLE
SOURCE          DF                SS                    MS    OVERALL F
------------------------------------------------------------
TOTAL           5            4.222393756
REGRESSION      1            3.856998683    3.856998683    42.2227
RESIDUAL        4            0.365395073    0.091348768
------------------------------------------------------------

THE OVERALL CONFIDENCE IS       0.995816937
THE PER CENT OF ERROR EXPLAINED IS          91.34625774

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS      19.38
THE AVERAGE ERROR IS            0.225599304

OBSERV      EST Y       TRUE Y       ERROR       % ERROR      NAME
  1         0.92        1.50         0.58        38.83       63AA0R
  2         0.53        0.60         0.07        10.86       63AA0T
  3         0.50        0.40        -0.10       -24.48       65AA0R
  4         0.50        0.40        -0.10       -24.48       65AA0T
  5         2.46        2.30        -0.16        -7.10       74AB0R
  6         3.65        3.30        -0.35       -10.51       74AC0T

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION
    VAR         PARTIAL F STAT        CONF.        NAME

 1              42.22277712    0.995816937   COMPLEX
```

Bench Check and Repair Elapsed Time

BCRT* = (FIAT + FIXT)/(Efficiency)

where FIAT = Fault Isolate and Test Time = $.3237(\text{complexity})^{.6650}$

	OBSERVATIONS	CROSS REF: DATA PT
1	1	63AA0R
2	2	63AA0T
3	3	65AA0R
4	4	65AA0T
5	5	74AB0R
6	6	74AC0T

THE INPUT VARIABLES ARE

N	BCFIT Y	COMPLEX X 1	N
1	2.00	8.80	1
2	0.90	3.80	2
3	0.60	3.40	3
4	0.60	3.40	4
5	3.90	40.90	5
6	5.00	75.30	6

*see p.29 for description of total equation. ANOVA table for BCRT on p.49.

Bench Check and Repair Elapsed Time(Continued):

----- REGRESSION OF INPUTS FOR OPTION 2   Y=a*X1↑b*X2↑c --------

CONFIDENCE LEVEL = 0.5

CORRELATION MATRIX (Y is last column)

1.00000	0.97046
0.97046	1.00000

----------------------------- NEXT ITERATION ----------------------

CONFIDENCE OF VARIABLE 1 ENTERED IS 0.997590763 F = 64.72737243

VARIABLE	COEF	STAND ERR	NAME
1	0 665024030	0.082659610	COMPLEX
CONSTANT	0 323729658		

ANOVA TABLE

SOURCE	DF	SS	MS	OVERALL F
TOTAL	5	4.383639509		
REGRESSION	1	4.12850742	4.12850742	64.727
RESIDUAL	4	0.255132088	0.063783022	

THE OVERALL CONFIDENCE IS 0.997590763

THE PER CENT OF ERROR EXPLAINED IS 94.17990262

NO OTHER VARIABLES CAN BE ADDED

THE AVERAGE % ERROR IS 17.34

THE AVERAGE ERROR IS 0.301959725

OBSERV	EST Y	TRUE Y	ERROR	% ERROR	NAME
1	1.37	2.00	0.63	31.25	63AA0F
2	0.79	0.90	0.11	12.60	63AA0T
3	0.73	0.60	-0.13	-21.75	65AA0R
4	0.73	0.60	-0.13	-21.75	65AA0T
5	3.82	3.90	0.08	2.06	74AB0F
6	5.73	5.00	-0.73	-14.64	74AC0T

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION

VAR	PARTIAL F STAT	CONF.	NAME
1	64.72737243	0.997590763	COMPLEX

Integrated Test Adaptor Cost

$$ITAC = 3919(\text{complexity})^{.4401}$$

OBSERVATIONS	CROSS REF:	DATA PT
1	1	63AA0R
2	2	63AA0T
3	3	65AA0R
4	4	65AA0T
5	5	74AB0
6	6	74AC0
7	7	62CA0R
8	8	62CA0T
9	9	71AA0R
10	10	71AA0T
11	11	71BA0

THE INPUT VARIABLES ARE

N	ITA Cost Y	COMPLEX X 1	N
1	16727.00	8.80	1
2	7169.00	3.80	2
3	4699.00	3.40	3
4	4699.00	3.40	4
5	19987.00	40.80	5
6	21264.00	75.30	6
7	16253.00	7.10	7
8	6965.00	3.00	8
9	11684.00	12.20	9
10	7790.00	8.10	10
11	7668.00	4.50	11

(continued p. 51)

Integrated Test Adaptor Cost(Continued):

----- REGRESSION OF INPUTS FOR OPTION 2 Y=a*X1↑b*X2↑c --------
CONFIDENCE LEVEL = 0.5

CORRELATION MATRIX (Y is last column)

1.00000	0.83781
0.83781	1.00000

------------------------------ NEXT ITERATION ------------------------
CONFIDENCE OF VARIABLE 1 ENTERED IS 0.998401447 F = 21.19386615

VARIABLE	COEF	STAND ERR	NAME
1	0.440124445	0.095602753	COMPLEX
CONSTANT	3919.226446		

ANOVA TABLE

SOURCE	DF	SS	MS	OVERALL F
TOTAL	10	3.087453208		
REGRESSION	1	2.16716434	2.16716434	21.1938
RESIDUAL	9	0.920288867	0.102254319	

THE OVERALL CONFIDENCE IS 0.998401447
THE PER CENT OF ERROR EXPLAINED IS 70.19262139

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS 20.90
THE AVERAGE ERROR IS 2320.138875

OBSERV	EST Y	TRUE Y	ERROR	% ERROR	NAME
1	10206.82	16727.00	6520.18	38.98	63AA0R
2	7053.06	7169.00	115.94	1.62	63AA0T
3	6716.10	4699.00	-2017.10	-42.93	65AA0R
4	6716.10	4699.00	-2017.10	-42.93	65AA0T
5	20048.93	19987.00	-61.93	-0.31	74AB0
6	26255.71	21264.00	-4991.71	-23.47	74AC0
7	9286.67	16253.00	6966.33	42.86	62CA0R
8	6356.13	6965.00	608.87	8.74	62CA0T
9	11785.12	11684.00	-101.12	-0.87	71AA0R
10	9841.17	7790.00	-2051.17	-26.33	71AA0T
11	7597.93	7668.00	70.07	0.91	71BA0

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION

VAR	PARTIAL F STAT	CONF.	NAME
1	21.19386615	0.998401447	COMPLEX

Test Software Cost

SWC = 9867 + 1431(complexity)

	OBSERVATIONS CROSS REF:	DATA PT	I
1	1	63AA0R	
2	2	63AA0T	
3	3	65AA0R	
4	4	65AA0T	
5	5	74AB0	
6	6	74AC0	
7	7	62CA0R	
8	8	62CA0T	
9	9	71AA0R	
10	10	71AA0T	

THE INPUT VARIABLES ARE

N	SW Cost Y	COMPLEX X 1	N
1	32929.00	8.80	1
2	14113.00	3.80	2
3	15341.00	3.40	3
4	15341.00	3.40	4
5	77358.00	40.80	5
6	113662.00	75.30	6
7	27150.00	7.10	7
8	11636.00	3.00	8
9	17165.00	12.20	9
10	11444.00	8.10	10

(continued p. 53)

Test Software Cost(Continued):

----- REGRESSION OF INPUTS FOR OPTION 1 Y=a+b*X1+c*X2 --------
CONFIDENCE LEVEL = 0.5

CORRELATION MATRIX (Y is last column)

1.00000	0.97765
0.97765	1.00000

------------------------------ NEXT ITERATION ----------------------

CONFIDENCE OF VARIABLE 1 ENTERED IS 0.99997493 F = 173.0123672

VARIABLE	COEF	STAND ERR	NAME
1	1431.396598	108.8231784	COMPLEX
CONSTANT	9867.030441		

ANOVA TABLE

SOURCE	DF	SS	MS	OVERALL F
TOTAL	9	1.06567E+10		
REGRESSION	1	1.01857E+10	1.01857E+10	173.01
RESIDUAL	8	470981184.5	58872648.07	

THE OVERALL CONFIDENCE IS 0.99997493
THE PER CENT OF ERROR EXPLAINED IS 95.58041248

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS 25.81
THE AVERAGE ERROR IS 5578.032766

OBSERV	EST Y	TRUE Y	ERROR	% ERROR	NAME
1	22463.32	32929.00	10465.68	31.78	63AA0R
2	15306.34	14113.00	-1193.34	-8.46	63AA0T
3	14733.78	15341.00	607.22	3.96	65AA0R
4	14733.78	15341.00	607.22	3.96	65AA0T
5	68268.01	77358.00	9089.99	11.75	74AB0
6	117651.19	113662.00	-3989.19	-3.51	74AC0
7	20029.95	27150.00	7120.05	26.22	62CA0R
8	14161.22	11636.00	-2525.22	-21.70	62CA0T
9	27330.07	17165.00	-10165.07	-59.22	71AA0R
10	21461.34	11444.00	-10017.34	-87.53	71AA0T

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION

VAR	PARTIAL F STAT	CONF.	NAME
1	173.0123675	0.99997493	COMPLEX

Technical Order Pages

$$TOP = 69.64(\text{complexity})^{.4366}$$

THE INPUT VARIABLES ARE

N	PAGES Y	COMPLEX X 1	N
1	88.00	3.10	1
2	140.00	3.40	2
3	102.00	3.60	3
4	140.00	3.40	4
5	206.00	7.20	5
6	164.00	9.00	6
7	328.00	34.00	7
8	362.00	78.00	8
9	371.00	41.00	9
10	550.00	75.00	10

(continued p. 55)

Technical Order Pages(Continued) :

```
----- REGRESSION OF INPUTS FOR OPTION 2    Y=a*X1↑b*X2↑c  -------
        CONFIDENCE LEVEL =  0.5


CORRELATION MATRIX  (Y is last column)
    1.00000    0.95300
    0.95300    1.00000


------------------------------ NEXT ITERATION ---------------------
CONFIDENCE OF VARIABLE  1     ENTERED IS      0.999901066    F =
 79.15527883


VARIABLE            COEF              STAND ERR      NAME
 1              0.436556126    0.049068202   COMPLEX
CONSTANT        69.64481206


ANOVA TABLE
SOURCE          DF                 SS                   MS   OVERALL
------------------------------------------------------------------
TOTAL           9               3.412347387
REGRESSION      1               3.099127357    3.099127357    79.15
RESIDUAL        8               0.313220030    0.039152504
----------------------------------------------------

THE OVERALL CONFIDENCE IS       0.999901066
THE PER CENT OF ERROR EXPLAINED IS            90.82098055

NO OTHER VARIABLES CAN BE ADDED
THE AVERAGE % ERROR IS      16.17
THE AVERAGE ERROR IS           36.50707500

OBSERV        EST Y       TRUE Y       ERROR        % ERROR      NAME
  1         114.13       88.00       -26.13       -29.69
  2         118.83      140.00        21.17        15.12
  3         121.83      102.00       -19.83       -19.44
  4         118.83      140.00        21.17        15.12
  5         164.88      206.00        41.12        19.96
  6         181.75      164.00       -17.75       -10.82
  7         324.69      328.00         3.31         1.01
  8         466.55      362.00      -104.55       -28.88
  9         352.34      371.00        18.66         5.03
 10         458.63      550.00        91.37        16.61

PARTIAL SIGNIFICANCE OF VARIABLES IN REGRESSION
     VAR          PARTIAL F STAT         CONF.        NAME

 1                79.15527886     0.999901066    COMPLEX
```